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DISTRIBUTION AND RELATIVE IMPORTANCE OF VARIOUS FUNGI ASSOCIATED WITH PEA ROOT-ROT IN COMMERCIAL PEA-GROWING AREAS IN NEW YORK

O. A. REINKING

IMPERIAL MYCOLOGICAL INSTITUTE
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ABSTRACT

BEFORE any sound recommendations for control of pea root-rot can be made for all pea-growing areas in New York State, it is necessary to determine which fungi are causing the disease, whether the same fungi are causing the disease in all localities, what effect soil and weather conditions have on the prevalence and destructiveness of these fungi and what soil management practices will do the most to prevent pea root-rot. The results of the field surveys and of the laboratory tests to aid in a determination of the above points are presented in this bulletin.

Isolations and microscopic examinations have shown that practically all root-rot organisms reported on peas in the United States and from various parts of the world are widely distributed in the older pea soils of western New York. The following organisms listed in order of importance are primarily responsible for disease in peas in New York State: *Fusarium solani* v. *martii* f. *2, Aphanomyces euteiches, Pythium ultimum, Rhizoctonia solani,* and *Ascochyta pinodella.* None of the other fungi commonly associated with root-rot were found to cause serious disease under greenhouse or field conditions.

The destructive organisms and disease were found in a wide range of soils with reactions ranging from pH 6.25 to 7.48 and in a few soils with a pH of 5.4 and 5.5.

Fusarium solani v. *martii* f. *2, Pythium ultimum,* and *Rhizoctonia solani* were found to be indigenous to certain virgin pea soils. The first two organisms were shown to multiply in the soil with repeated pea plantings. Apparently the severity of root-rot depends upon the build-up of destructive fungi.

A 6-year study of fields on the Station's canning crops farm at Geneva where peas have been grown in rotation over a period of 16 years showed that the important root-rot organisms were not entirely eliminated by a 3-, 4-, or 5-year rotation. Nevertheless, profitable yields were obtained during favorable growing seasons on the sufficiently fertilized fields in spite of the presence of pathogens.

One strain of *Fusarium solani* v. *martii* f. *2* isolated from root-rot of a California red kidney bean was found to be extremely pathogenic to peas and capable of attacking and living as a weaker parasite on various dry beans. The latter, therefore, should be excluded from a rotation in fields where peas are to be planted.

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O. A. REINKING
Professor and Head of Division of Plant Pathology

INTRODUCTION

ONE of the most persistent and destructive diseases of peas in New York State is root-rot. When present, it is apparently a factor in reducing yields even tho the plants may not be killed outright. During a dry season, the disease is more in evidence because the plants become yellow as a result of injury to the root system which interferes with its efficiency in procuring water. A severe rot of the foot and root of plants, often resulting in death, may be produced during a very wet period. In normal seasons plants may be affected, but profitable yields may yet be obtained.

The disease has been reported from most pea-growing areas in the United States (3, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16)[1] and in other countries (2, 18, 24, 25, 26, 27) as well. The reports from these localities show that it may be caused by any one of several different fungi. Those most commonly designated and listed in order of their importance are *Aphanomyces euteiches* Drechs. (3, 5, 6, 7, 8, 9, 13, 15, 22); *Fusarium solani* (Mart.) v. *martii* (App. et Wr.) Wr. f. *2* Sny. (12, 15, 23); *Corticium vagum* B. et C. var. *solani* Burt *(Rhizoctonia solani* Kühn) (14, 19); *Pythium ultimum* Trow. (11, 15); and *Ascochyta pinodella* Jones (16).

In addition, several other less widely distributed fungi have been reported as capable of causing a similar type of trouble. Among these are *Fusarium coeruleum* (Lib.) Sacc. in the United States (10); *Fusarium avenaceum* (Fr.) Sacc. (*F. viticola* Thüm.) in Sweden (26); *Pythium irregulare* Buis., *F. anguioides* Sherb., *F. avenaceum* (Fr.) Sacc. [(*F. herbarum* (Cda.) Fr. and *F. herbarum* (Cda.) Fr. v. *viticola* (Thüm.) Wr.)], *F. equiseti* (Cda.) Sacc., *F. solani* (Mart.)

[1]Figures in parenthesis refer to Literature Cited, page 42.

App. et Wr. (*F. solani* (Mart.) v. *medium* Wr.), *F. solani* (Mart.) v. *striatum* (Sherb.) Wr., *F. solani* (Mart.) v. *martii* (App. et Wr.) Wr., *F. culmorum* (W.G.Sm.) Sacc., and *F. oxysporum* Schl. in Holland (2, 27); *F. avenaceum* (Fr.) Sacc., *F. solani* (Mart.) v. *martii* (App. et Wr.) Wr., *F. culmorum* (W.G.Sm.) Sacc., *Gibberella saubinetii* (Mont.) Sacc. (*F. graminearum* Schw.), *Fusarium* spp., *Botrytis cinerea* Pers., *Helminthosporium sativum* P. K. et B., *Ophiobolus heterostrophus* Drechs., and *Sclerotinia* sp. in England pathogenic to pea cotyledons (18); and *F. arthrosporioides* Sherb., *F. sporotrichioides* Sherb., and *F. anguioides* Sherb. in Japan (24, 25).

In New York State, most of these organisms were found associated with diseased peas, especially in the areas where peas had been grown for many years. Apparently, the disease fungi become more prevalent after peas have been grown for several years, particularly in fields where a proper rotation with other crops has not been practiced. On the other hand, profitable crops are still being produced on some well-managed farms that have been growing peas for the last 50 years.

Because of the importance of the problem, studies were begun to determine the best method of avoiding the disease. Before any sound recommendations could be made for all pea-growing areas in the State, it was necessary to determine whether the same fungi were causing the disease in all localities, what effect soil and weather conditions had on the prevalence and destructiveness of these fungi, and what soil management practices would do the most to prevent pea root-rot. The results of the field surveys made during 1931 to 1941 to determine the cause of root-rot and prevalence of the causal fungi and of laboratory tests to determine the virulence of the organisms from different soils are presented in this bulletin.

MATERIALS AND METHODS

The organisms associated with root-rot were determined by laboratory diagnosis of severely diseased plants collected from commercial fields in western New York during 1931 to 1941, inclusive. Samples were obtained from as many different localities and soil types as possible. Special attention was paid to organisms present from year to year (1937 to 1941) on Ontario loam near Geneva, silty clay loam bottom land near Mt. Morris, and silty clay loam upland adjacent to the latter area.

Diseased roots collected from 1931 to 1936 were washed in a modified Simmon's device (21) and placed on potato dextrose agar or

oatmeal agar to secure pure cultures of the fungi. Material collected from 1936 thru 1941 was cultured on ordinary potato dextrose agar, potato dextrose agar plus 1 drop of a 50 per cent lactic acid solution, and plates of corn meal made by sterilizing in the autoclave equal amounts by volume of corn meal and water in petri dishes. The plain agar plate method made it possible to detect almost all fungi and bacteria present, but had the disadvantage of allowing bacteria to grow freely. The Fusaria, Ascochytas, Rhizoctonias, and many Pythiums grew readily on these plates.

The acid agar plates inhibited the growth of bacteria and were useful in the isolation of Fusaria and fungi in general other than *Aphanomyces euteiches* and the *Pythium* spp. The corn meal plates were found to be excellent for the isolation of Pythium and Rhizoctonia as well as Fusaria. Since this process failed to reveal *A. euteiches,* the direct microscopic examination of diseased material, which had been placed in a tube of water for a few days, was utilized. This method allowed characteristic spores of the fungus, if present, to develop. The latter could be identified easily by their distinctive morphological characters. Also, the microscopic method of examination showed the presence of Rhizoctonia and frequently the presence of Fusaria.

Isolations of *Aphanomyces euteiches* were made following the technic devised by Drechsler (4) in which the fungus from the diseased tissue was allowed to grow for a few days in a plate of sterilized water and then dried between blotting paper and plated on potato dextrose agar. Examination of the growth on the plate with a microscope made it possible to detect the mycelium of Aphanomyces and to transfer a portion.

Inoculation tests with the various fungi were made in nutrient culture solutions, in pots of infested soil in a climate laboratory with controlled temperature and moisture, and in pots of infested soil placed in the greenhouse. The nutrient culture solution method followed was similar to that used by Broadfoot and Tyner (1) for wheat root-rot. The nutrient solution contained the following amounts of a molar solution per liter of the various chemicals: 5 cc of $Ca(NO_3)_2$, 5 cc of KNO_3, 2 cc of $MgSO_4$, and 1 cc of KH_2PO_4. To this was added 1 cc of a 0.5 per cent solution of ferric tartrate twice a week during the test. The peas were first germinated on blotters for about 1 week until good roots were developed. Ten healthy plants were then inoculated by immersing the roots for 48 hours in a 1-week-old culture of the fungus in question grown in the above nutrient solution to which had been added dextrose to make a 1 per cent solution. After 48 hours in the inoculum, the plants were arranged on paraffined wire-mesh screens and transferred to fresh nutrient solution in beakers for final results (Fig. 3). The method was used even tho it may favor the fungus and its by-products, because it usually gave a rapid indication of pathogenicity.

The plants in the climate laboratory were grown in double-walled, auto-irrigating pots that held a constant soil moisture of 22 per cent (dry weight basis) and were held at a constant temperature of 18° C under artificial illumination (Fig. 4). At about blossoming time, the plants were dug, examined for root-rot, and used for laboratory diagnosis. The greenhouse tests were run in 6-inch pots placed in sphagnum moss on a bench and held at a temperature of 65° to 75° F and watered as needed.

Cultures of the various fungi used for infesting the pots of sterilized soil, with the exception of *Aphanomyces euteiches,* were grown in the main in a sterilized mixture of from 25 to 50 per cent corn meal and a sandy soil. In a number of the first inoculation tests, the soil was infested with a culture of the fungus growing on sterilized wheat grains. The inoculum in both instances was merely incorporated in the top 2 to 3 inches of soil in each pot. The pea seeds were planted to a depth of 1½ to 2 inches. Re-isolations from diseased tissues were made in all tests.

DISTRIBUTION OF FUNGI ASSOCIATED WITH ROOT-ROT

DISTRIBUTION AS TO LOCALITIES AND COUNTIES

At least 14 different fungi were isolated from diseased plants collected from 1931 thru 1941 from fields in western New York (Table 1). One or more of these fungi has been associated with severely diseased plants in 63 different localities in 15 counties. According to tests for virulence, as discussed later, the first five organisms listed are the chief pathogens. Of these *Fusarium solani* v. *martii* f. *2* was most common, followed by *Aphanomyces euteiches, Pythium ultimum,* and *Rhizoctonia solani.* Since a special technic is required to reveal *A. euteiches,* a negative report from 1925 thru 1936 does not mean necessarily that it was not present. In fact, it may have been widely distributed because it was found in almost 60 per cent of the fields during the wetter seasons from 1937 thru 1941 when plants were critically examined under the microscope. *Ascochyta pinodella* is not widespread since it was isolated only once in 1937 from a field near Penn Yan, twice in 1938 from Mt. Morris and Geneva, three times in 1940 from Ontario, Orleans, and Wayne counties, and once in 1941 from Ontario County. In addition to these widely distributed pathogens, others, such as *F. poae, F. sporotrichioides, F. arthrosporioides, F. anguioides, F. scirpi* v. *acuminatum, F. equiseti, F. culmorum, F. graminearum,* and *F. oxysporum,* were found to be quite generally present. The last-named fungus was isolated from

TABLE 1.—DISTRIBUTION OF FUNGI ASSOCIATED WITH ROOT-ROT OF PEAS AS REVEALED BY ISOLATIONS AND MICROSCOPIC EXAMINATIONS, 1924 TO 1941.

COUNTY	TOWN	*F. solani* v. *martii* f. 2	*A. euteiches*	*P. ultimum*	*R. solani*	*A. pinodella*	*F. poae*	*F. sporotrichioides*	*F. arthrosporioides*	*F. anguioides*	*F. scirpi* v. *acuminatum*	*F. equiseti*	*F. culmorum*	*F. graminearum*	*F. oxysporum*
					1924*										
Erie	Eden		x												
	Hamburgh		x	x											
Livingston	Mt. Morris		x			x									
Monroe	Brockport			x											
	Churchville			x											
Nassau	Mineola		x												
					1925–27†										
Ontario	Geneva					x									
					1931‡										
Onondaga	Apulia			x											
	Canastota				x										
Ontario	Geneva	x		x	x					x		x			x
					1932										
Ontario	Geneva	x		x	x			x	x	x	x	x			x
Wayne	N. Rose	x													x
					1933										
Genesee	LeRoy				x										
Ontario	Geneva				x					x					
					1935										
Ontario	Geneva	x		x	x				x	x	x	x		x	x
	Hall							x							x
					1936										
Ontario	Geneva	x													x
					1937										
Cayuga	Montezuma				x										x
Chautauqua	Fredonia	x													
Jefferson	Adams						x					x			
Livingston	Avon											x			x
	Mt. Morris	x	x	x	x										x
Oneida	S. Sangerfield	x	x				x								x
Ontario	Geneva	x	x		x						x	x			x
Orleans	Albion	x	x	x	x		x				x				x
	Fancher	x										x			
	Medina			x											
Wayne	Sodus		No	x							x	x			x
	Sodus Center		No	x							x				x
Wyoming	Perry	x	x	x	x		x	x		x	x				x
Yates	Penn Yan	x	No	x	x	x		x	x	x		x	x		x

**A. euteiches* reported by Drechsler (3). *P. ultimum* and *A. pinodella* listed as such from data submitted by Prof. Charles Chupp of Cornell University recording the presence of Pythium and a Phoma.

†Investigations confined to a study of Ascochyta blight by Jones (16).

‡Isolation of fungi from 1931 thru 1935 made under the direction of Dr. J. G. Horsfall and identifications made by the writer.

TABLE 1.—DISTRIBUTION OF FUNGI ASSOCIATED WITH ROOT-ROT OF PEAS AS REVEALED BY ISOLATIONS AND MICROSCOPIC EXAMINATIONS, 1924 TO 1941. (*Concluded.*)

COUNTY	TOWN	*F. solani* v. *martii* f. 2	*A. euteiches*	*P. ultimum*	*R. solani*	*A. pinodella*	*F. poae*	*F. sporotrichioides*	*F. arthrosporioides*	*F. anguioides*	*F. scirpi* v. *acuminatum*	*F. equiseti*	*F. culmorum*	*F. graminearum*	*F. oxysporum*
						1938									
Livingston	Mt. Morris	x		x		x					x				x
	Groveland	x													x
Ontario	Geneva, Pre-emption Rd.	x			x										x
	Geneva	x		x	x	x				x	x	x			x
	Hall	x			x		x								x
	South Gorham														x
Orleans		x			x										x
Yates		x	x								x				x
						1939									
Livingston	Avon	x	No												x
	Mt. Morris	x	No	x	x		x			x	x				x
	Nunda	x	x	x	x										x
Ontario	Geneva	x	No	x	x		x			x	x				x
						1940									
Erie	North Collins	x						x					x		x
Livingston	Avon	x	x												x
	Mt. Morris	x	x	x	x			x				x			x
	Nunda	x	x	x											x
Monroe	Morton	x	No		x										x
Onondaga	Dunham	x	No	x											x
Ontario	Geneva	x	x	x	x	x		x		x	x	x			x
	Kashong, Pre-emption Rd.	x	x	x				x							x
	Junius	x	No	x	x							x			x
Orleans	Medina	x	x	x	x	x									x
Wayne	Sodus	x	x			x		x							x
Wyoming	Castile	x	x	x	x										x
	Perry	x	No												x
	Warsaw	x	x												x
Yates	Rushville	x	No	x											x
						1941									
Onondaga	Elbridge	x		x	x										x
	Memphis	x			x										x
Ontario	Gorham	x			x										x
	Geneva	x	x	x	x	x									x
Yates	Penn Yan	x		x											x

almost all diseased plants studied. In most cases, all of these organisms were associated with one or more of the pathogenic fungi already listed. They are not sufficiently pathogenic to cause disease by themselves on normally healthy plants as revealed in the virulence tests discussed later.

DISTRIBUTION AS TO SOIL TYPE AND SOIL REACTION

From 1937 thru 1941, detailed field surveys, isolations, and microscopic examinations of diseased peas were made from fields with known soil textures and pH concentrations. All fields from which infected plants were taken were badly infested in spots or thruout the entire field. Samples of soil were collected, dried, and classified as to type. The reaction of the soil was determined by the quinhydrone or glass electrode method. Data on the soil conditions and the occurrence of the five pathogenic fungi in severely diseased fields in 57 localities are given in Table 2. The percentage occurrence of each fungus in diseased plants is only an approximate figure, but it indicates the relative presence of each fungus.

The diseased fields had soils ranging from pH 5.4 to 7.48. In 1937, *Fusarium solani* v. *martii* f. *2* and *Aphanomyces euteiches* were isolated from plants growing in all soil types, *Pythium ultimum* from most of them, and *Rhizoctonia solani* from all except the medium acid Fox gravelly loam (pH 5.41). *Ascochyta pinodella* was found only in the Penn Yan area. Investigations in 1938 were not extensive, but *F. solani* v. *martii* f. *2* was present in all areas and the next three fungi listed in Table 2 were present in the Ontario loam. Since all specimens were not examined under the microscope, *A. euteiches* may have escaped detection in the other localities. During the extremely dry season of 1939, *F. solani* v. *martii* f. *2* was found in all fields and *P. ultimum* and *R. solani* in most, but *A. euteiches* was present only in the slightly acid silty clay loam at Nunda which was favored with more rain.

In contrast to these findings, the 1940 survey revealed *Aphanomyces euteiches* in practically every field. As a matter of fact, *Fusarium solani* v. *martii* f. *2* was widespread and *Pythium ultimum* and Rhizoctonia were found to a lesser degree in all soil types. *Ascochyta pinodella* was found in plants growing on a silty clay loam (pH 7.25) at Geneva, a fine sandy loam (pH 6.35) at Sodus, and a silt loam (pH 6.5) at Medina. Altho peas are supposed to be favored by alkaline soils, some of the alkaline fields were severely diseased. In 1940,

TABLE 2.—DISTRIBUTION OF PATHOGENS ACCORDING TO SOIL TYPE AND SOIL REACTION.

LOCATION	SOIL TYPE	pH	VARIETY	APPROXIMATE PERCENTAGE OCCURRENCE IN DISEASED PLANTS				
				F. solani v. *martii* f. 2	*A. euteiches*	*P. ultimum*	*R. solani*	*A. pinodella*
			1937					
Geneva	Ontario loam	7.25	Rogers Chief	50	100	—	—	—
Geneva	Ontario loam	7.25	Asgrow Canners King	100	—	—	—	—
Geneva	Ontario loam	7.25	Pride	20	None	—	100	—
Penn Yan	Clay loam	6.78	Rogers Climax	9	None	50	1	6
S. Sangerfield	Fox gravelly loam	5.41	Surprise	25	25	—	—	—
Mt. Morris	Silty clay loam, bottom land	6.80	Woodruff Topper	—	Present	—	Present	—
Mt. Morris	Silty clay loam, bottom land	6.80	Surprise and Thos. Laxton	42	Present	—	17	—
Albion	Fine sandy loam	6.5	Surprise	40	Present	33	67	—
Perry	Silty clay loam, upland	6.42	Thos. Laxton	33	75	10	10	—
			1938					
Geneva	Ontario loam	7.1	Perfection	58	Present	18	4	5
Geneva	Ontario loam	7.19	Rogers Ace	33	None	—	33	—
Geneva	Ontario loam	6.90	Rogers Ace	67	None	—	50	—
Seneca Castle	Ontario loam	6.80	Climax	33	—	—	67	—
Hall	Ontario loam	7.26	Perfection and Penin	22	—	—	22	—
Benton	Ontario loam	6.9	Teton	100	Present	—	—	—
Mt. Morris	Silty clay loam, bottom land	6.8	Surprise	67	—	—	—	—
Mt. Morris	Silty clay loam, bottom land	6.8	Thos. Laxton	60	—	—	—	—
Groveland	Silty clay loam	6.6	Thos. Laxton	100	—	—	—	—

			1939					
Geneva	Ontario loam	7.25	Wis. Early Sweet	30	None	9	11	—
Geneva	Ontario loam	7.10	Surprise	64	None	20	—	—
Geneva	Silty clay loam	7.25	Pride	83	None	10	5	—
Mt. Morris	Silty clay loam, bottom land	7.20	Thos. Laxton	48	None	10	5	—
Mt. Morris	Silty clay loam, bottom land	7.20	Glacier	44	None	1	1	—
Mt. Morris	Silty clay loam	6.60	Variety test	38-100	None	25	—	—
Avon	Silty clay loam, bottom land	7.20	——— ———	Present	None	—	—	—
Nunda	Silty clay loam, upland	6.25	Telephone	29	80	—	6	—
Nunda	Silty clay loam, upland	6.25	Thos. Laxton	20	64	1	6	—
			1940					
Geneva	Silty clay loam	7.25	Thos. Laxton	52	60	3	—	—
Geneva	Silty clay loam	7.25	Surprise	100	100	21	26	2
Geneva	Silty clay loam	7.25	Pride	100	83	70	70	—
Geneva	Ontario loam	6.92	Thos. Laxton	100	100	100	—	—
Geneva	Ontario loam	6.92	Surprise	100	100	100	—	—
Geneva	Ontario loam	6.90	Pride	100	50	—	50	—
Geneva	Ontario loam	6.90	Thos. Laxton	100	100	—	100	—
Geneva	Ontario loam	7.25	Pride	100	100	—	—	—
Rushville	Fine sandy loam	6.78	Wis. Early Sweet	50	None	50	—	—
Sodus	Fine sandy loam	6.35		100	100	—	—	100
Medina	Silt loam	6.5	Thos. Laxton	100	75	25	25	25
Medina	Silt loam	6.5	Green Admiral	100	100	67	—	—
Mt. Morris	Silty clay loam, bottom land	6.82	Surprise	100	100	100	—	—
Mt. Morris	Silty clay loam, bottom land	6.80	Thos. Laxton	100	100	100	—	—
Mt. Morris	Silty clay loam, bottom land	6.80	Canners King	100	100	—	—	—
Mt. Morris	Silty clay loam, bottom land	7.48	Surprise	100	50	100	50	—

TABLE 2.—DISTRIBUTION OF PATHOGENS ACCORDING TO SOIL TYPE AND SOIL REACTION. (*Concluded.*)

LOCATION	SOIL TYPE	pH	VARIETY	APPROXIMATE PERCENTAGE OCCURRENCE IN DISEASED PLANTS				
				F. solani v. *martii* f. 2	*A. euteiches*	*P. ultimum*	*R. solani*	*A. pinodella*
			1940					
Mt. Morris	Silty clay loam, bottom land	7.15	Pride	100	100	—	100	—
Mt. Morris	Silty clay loam, bottom land	6.80	Variety test	75	40	—	81	—
Dansville	Silty clay loam, bottom land	6.99	Thos. Laxton	100	None	100	—	—
Nunda	Silty clay loam, upland	6.68	Thos. Laxton	100	100	—	—	—
North of Nunda	Silty clay loam, upland	6.60	Thos. Laxton	100	100	100	—	—
Castile	Silty clay loam, upland	6.60	Perfection	100	100	100	100	—
Castile	Silty clay loam, upland	6.60	Surprise	100	100	—	—	—
Warsaw	Silt loam	6.50	Surprise	100	100	—	—	—
North Collins	Silt loam	6.45	Thos. Laxton	100	100	—	—	—
			1941					
Geneva	Ontario loam	7.25	Variety test	95	40	25	25	—
Geneva	Silty clay loam	7.2	Surprise	90	35	25	25	25
Geneva	Ontario loam	7.0	Surprise	25	None	20	25	—
Gorham	Ontario loam	7.0	Surprise	100	None	—	20	—
Penn Yan	Clay loam	5.5	Surprise	100	None	25	—	—

the diseased plants in a field of Surprise at Mt. Morris with a pH of 7.48 had 100 per cent infection with *F. solani* v. *martii* f. *2,* 50 per cent with *A. euteiches,* 100 per cent with *P. ultimum,* and 50 per cent with *R. solani.* All plants were overrun with the pathogens, producing about 100 per cent field infection. In 1941, *F. solani* v. *martii* f. *2, P. ultimum,* and *R. solani* were as widely distributed as usual, but *A. euteiches* was only found in the old pea lands on Ontario clay loam and the silty clay loam near Geneva.

Except for the dry season of 1939, there was not much difference in the prevalence of *Fusarium solani* v. *martii* f. *2* and *Aphanomyces euteiches* in all soil types examined. *Pythium ultimum* and *Rhizoctonia solani* were found quite generally in all soils but to a lesser degree. *Ascochyta pinodella* was found only occasionally, indicating that it is not widespread.

DISTRIBUTION AS TO SEASONS

The season has a decided effect on *Aphanomyces euteiches* because it was practically absent in the dry year of 1939, widespread in the wet season of 1940, and not very common in the moderately dry season of 1941. On the other hand, *Fusarium solani* v. *martii* f. *2* was always present. The effect of seasonal conditions on these fungi can best be understood by an analysis of the data presented in Table 2 from Geneva, Mt. Morris, and Nunda for the years 1939 and 1940. During these years, detailed isolations were made from diseased fields of the same farms. The 1939 plantings of Wisconsin Early Sweet and Pride on the Station canning crops farm at Geneva had approximately 100 per cent root-rot. Isolations made of over 100 plants collected from each field showed the presence of *F. solani* v. *martii* f. *2, Pythium ultimum,* and *Rhizoctonia solani.* Microscopic examination showed that *A. euteiches* was absent. The same situation was found to be true of the Thomas Laxton and Glacier fields investigated at Mt. Morris. During the wet season of 1940, *A. euteiches* and all of the other fungi mentioned were readily obtained from diseased plants growing in a variety planting made on the Wisconsin Early Sweet location of the year before and in three adjoining fields on the canning crops farm at Geneva. Diseased plants collected from areas adjoining the 1939 plantings on the Mt. Morris bottom lands gave similar findings. Apparently, *A. euteiches* did not cause damage in the dry seasons even tho it had been generally distributed in these areas. A greater percentage of the plants in diseased fields were infected with *P. ulti-*

mum, R. solani, and *Ascochyta pinodella* in the wetter season of 1940 than in the drier season of 1939.

EFFECT OF PEA CULTURE ON PREVALENCE AND DESTRUCTIVENESS OF ROOT-ROT FUNGI

PRESENCE OF FUNGI IN VIRGIN SOIL AND IN SOIL NEW TO PEA CULTURE

The almost universal presence of *Fusarium solani* v. *martii* f. *2* and *Pythium ultimum* in fields of peas planted under a variety of conditions, including land apparently new to pea culture, indicated that these two organisms may be indigenous to certain soils. In order to prove this assumption, a fine, sandy loam soil with a pH of 7.0 was collected from a piece of woodland that was higher than the surrounding land and had not been subject to wash from cultivated soils. The soil was placed in 80 formaldehyde-sterilized pots in climate laboratory chambers. Sixteen pots were distributed in each of five chambers and planted with 25 Perfection seed from a stock that had always produced disease-free plants in steamed soil. After 19 days, the plants that developed from the 400 seeds in each chamber were dug and examined for root-rot. On an average in the five chambers, 4.6 per cent of the plants were affected with root-rot.

Isolations from these plants showed (Table 3) infection with *Pythium ultimum* in all chambers and with *Fusarium solani* v. *martii* f. *2* in four of the five. In infection tests discussed later, two of the strains of *P. ultimum* were found to be highly pathogenic. *F. poae* was isolated from one diseased plant and *F. oxysporum* strains were isolated from diseased plants in all chambers. The plants were removed and the pots in three chambers were replanted with Perfection peas. An increase in root-rot to 21.7 per cent of the plants was produced. Both pathogens, *F. solani* v. *martii* f. *2* and *P. ultimum*, were isolated from diseased plants. In this test after one crop of peas in virgin soil, the incidence of disease was raised from 4.6 to 21.7 per cent where *F. solani* v. *martii* f. *2* and *P. ultimum* occurred naturally.

These studies in the climate laboratory on the prevalence of fungi in virgin soil were confirmed in comparative duplicate variety tests made in heavily infested soil and in cultivated fields where peas had never been grown previously so far as could be determined. The variety planting in severely infested soil was located at Geneva in a silty clay loam with a pH that varied in spots from 7.25 to 7.5. This plot had been in peas the year previous. At Junius, about 5 miles away,

TABLE 3.—PREVALENCE OF FUNGI ON SEVERAL VARIETIES OF PEAS PLANTED IN A FIELD PREVIOUSLY CROPPED TO PEAS AND IN TWO FIELDS NEW TO PEA CULTURE IN 1940.

VARIETY	ISOLATIONS			
	F. solani v. *martii* f. 2	*A. euteiches*	*P. ultimum*	*R. solani*
Infested Soil, Silty Clay Loam, pH 7.25–7.5, Geneva				
Glacier	x	x		
Hybrid No. 82	x	x		
Dark Podded Telephone	x	x		
Alderman	x	x		
Thos. Laxton (dark-podded)	x	x		
Improved Gradus	x	x		
Surprise		x		x
Climax	x	x	x	
Chief	x			
Early Wales				
Walah (wilt-resist. Wales)	x			
Stuart Perfection	x			
Wis. Merit	x	x		x
Thos. Laxton	x			x
Improved Gradus, Strain 1	x	x		
Improved Gradus, Strain 2	x	x		
President Wilson	x	x	x	x
Gilbo	x			x
Hybrid No. 82				x
Alderman	x			
New Soil, Sandy Loam, pH 6.1, Junius				
Hybrid No. 82				
Dark Podded Telephone	x			x
Alderman	x			
Thos. Laxton (dark-podded)			x	x
Improved Gradus				
New Soil, Silty Clay Loam, pH 6.83, Morton				
Perfection				
Stuart Perfection				
Wis. Merit				
Thos. Laxton				
Improved Gradus, Strain 1	x			x
Improved Gradus, Strain 2	x			
President Wilson	x			
Gilbo	x			
Alderman				x
Rogers Climax	x			x

varieties of some of the same seed stock were planted in a sandy loam soil (pH 6.1) new to pea culture. A second test of some of the varieties made with different seed stock was planted in a silty clay loam with a pH of 6.83 at Morton. These tests, of necessity, were run on different

soil types under different climatic conditions. Tests run under identical conditions would have been preferred. Since it had been shown (Table 2), however, that there was no apparent difference in the ability of the various pathogens to live in and produce severe disease in the various soils of the types and reactions used, it is believed that the data secured are of significance.

Severe root-rot developed on 80 to 100 per cent of the plants of all varieties, except Early Wales, grown in the Geneva infested soil previously cropped to peas, while only a few scattering cases of infection occurred in the two soils new to pea culture. As shown in Table 3, isolations and microscopic examinations revealed the presence of *Fusarium solani* v. *martii* f. *2* and *Aphanomyces euteiches* in practically every variety planted in the old pea field at Geneva. *Pythium ultimum* and *Rhizoctonia solani* were present to a lesser degree. In the virgin soils at Junius and Morton, where only a few cases of disease developed, *F. solani* v. *martii* f. *2*, *P. ultimum*, and *R. solani* were isolated from several of the diseased plants. In infection tests discussed later, disease was produced with one strain of *F. solani* v. *martii* f. *2* obtained from the Junius planting. Therefore, these tests show quite conclusively that three of the disease fungi were present in the latter two virgin fields even tho they were not sufficiently numerous to cause a severe epidemic such as occurred in the field previously planted with peas. *A. euteiches* was not found in the few diseased plants present in the new soil. The severity of root-rot seems to depend upon the build-up of destructive fungi. It is important to determine, therefore, whether these fungi die out when peas are not grown for several years. Data on this point are being secured from fields on the Station's canning crops farm.

RELATION OF PATHOGENS AND DISEASE TO ROTATIONS AND FERTILIZER

For the past 16 years, rotation experiments with peas have been conducted by the Vegetable Crops Division of this Station on the canning crops farm. Some were run in conjunction with fertilizer tests and it was mainly upon these that data were obtained. The amount of fertilizer applications as they are related to yield will not be elaborated upon in these studies. The relationship between presence of pathogens and yield merely will be cited for the nonfertilized plots as compared with the highest yielding fertilized ones. Data relative to these factors covering a period of years from 1937 to 1941 obtained

from seven different fields on the same farm are presented in Table 4.[2] The soils were either Ontario loams or silty clay loams with a pH of approximately 7.25. All were thoroly infested with the important root-rot organisms.

Field No. 1 studied in this area was one that had been planted late, on May 11, 1937, with Roger's Chief and Canners' King peas. It had not been in peas for 4 years. Studies were made to show what pathogens were causing disease. In spite of a 5-year rotation, disease was scattered thruout and isolations showed the presence of *Fusarium solani* v. *martii* f. *2, Aphanomyces euteiches,* and *Pythium ultimum.* The late planting was made to secure peas for canning tests and was not harvested for yields. This same field was planted with Thomas Laxton peas in 1940 after having been in clover sod for 2 years and produced a profitable crop of 2,008 pounds per acre. The three most important pathogens mentioned above were still in the soil. Disease was scattered thruout the field, being severe in spots, and undoubtedly caused a reduction in the yield. Evidently, the favorable growing season outweighed the effect of the organisms and disease in the production of a profitable yield. No different fertilizer treatments were made.

No analyses of fields from a fungus standpoint were made during the favorable pea year of 1938. This was one of the best recent pea years in New York State which was reflected in the field No. 2 planting of Pride peas that produced 2,617 pounds on the unfertilized plat and 4,983 pounds on the fertilized plat. A 4-year crop rotation had been practiced on this field. Since all important pea pathogens were found to be present after a 4-year rotation in nearby fields on this farm, it may be inferred that all parasites were present in this soil because scattered disease was present.

In the very dry season of 1939, the field of Wisconsin Early Sweet peas was a failure because of dry weather, near wilt, and root-rot. An examination of diseased plants showed the presence of *Fusarium solani* v. *martii* f. *2, Pythium ultimum,* and *Rhizoctonia solani,* but not *Aphanomyces euteiches.* The first three pathogens again were present even tho a 4-year rotation was practiced. The latter organism as explained before, was inactive because of dry soil conditions. The Pride field examined that year received different fertilizer applica-

[2]The writer is indebted to C. B. Sayre, Head of the Division of Vegetable Crops at this Station, for the rotation and yield data.

TABLE 4.—EFFECT OF ROTATIONS AND FERTILIZERS ON PRESENCE AND DESTRUCTIVENESS OF ROOT-ROT FUNGI.

FIELD AND VARIETY	DATE PLANTED	NO. OF YEARS BETWEEN PEA CROPS	GROWING SEASON	YIELD, LBS. PER ACRE		ISOLATIONS			
				No fertilizer	Fertilized	*F. solani* v. *martii* f. 2	*A. euteiches*	*P. ultimum*	*R. solani*
Field 1:									
Rogers Chief	May 11, 1937	4	Poor	——	——	x	x		
Canners King	May 11, 1937	4	Poor	——	——	x		x	
Field 1:									
Thos. Laxton	Apr. 29, 1940	2	Good	——	2,008*	x	x	x	
Field 2:									
Pride	Apr. 21, 1938	3	Excellent	2,617	4,983†	–§	–§	–§	–§
Field 3:									
Wis. Early Sweet	Apr. 28, 1939	3	Very poor	——	Failure‡	x	None	x	x
Field 4:									
Pride	May 2, 1939	3	Very poor	542	1,505†	x	None	x	x
Field 5:									
Surprise	May 1, 1940	2	Good	1,341	1,817‡	x	x	x	x
Field 6:									
Pride	May 7, 1940	3	Good	783	1,798‡	x	x	x	x
Field 7:									
Surprise	Apr. 24, 1941	3	Good	1,772	3,290‡	x	x		x

*150 pounds per acre 4–16–4.
†600 pounds per acre 10–20–10.
‡600 pounds per acre 5–20–5.
§No isolations.

tions. The highest fertilized plat produced 1,505 pounds of peas, while the nonfertilized plat yielded only 542 pounds per acre. It is believed that the extremely dry season more than disease was responsible for these reductions in yields.

The more normal, wetter seasons of 1940 and 1941 showed the beneficial effects of rotation, weather, and fertilizer applications in fields that received a 3- and 4-year rotation in spite of the presence of the important root-rot organisms. In 1940, two fields of peas were studied. Disease in both was scattered and an analysis of diseased plants showed that *Fusarium solani* v. *martii* f. *2, Aphanomyces euteiches, Pythium ultimum,* and *Rhizoctonia solani* were present. Even tho this was the case, the planting of Surprise peas yielded 1,341 pounds per acre on the nonfertilized plat and 1,817 pounds on the highest fertilized plat. The Pride planting yielded 783 pounds on the nonfertilized plat and 1,798 pounds on the fertilized plat. In 1941, still better yields were obtained in the presence of all disease-producing organisms. Surprise yielded 1,772 pounds on the unfertilized plat and 3,290 pounds on the fertilized one. It is interesting to note that in the latter two years with the highest yields all pathogens were active in the fields, while in the drier year of 1939 with failures and low yields, one of the more important pathogens, *A. euteiches,* was inactive. These studies showed that the pathogens and disease were not eliminated by the 3-, 4-, or 5-year rotations practiced. They did not show what reduction took place. Undoubtedly, the population of the pathogens in the soil was reduced, for profitable yields were obtained on infested soil in spite of their presence when a proper fertilizer program had been practiced along with the rotation. Further studies on longer and different types of rotation appear to be essential in order to devise a crop rotation that would produce better results.

TYPE OF DISEASE CAUSED BY FUNGI

The field surveys showed that 14 different fungi were frequently present on rotted roots of peas. The five generally accepted pathogens were isolated most frequently, but in addition nine different Fusaria were often found associated with diseased plants. At times, three or four of these fungi were present in the same plant so that it was impossible to tell which was causing the disease. Because of this confused situation, several strains of each fungus from different localities were obtained in pure culture and tested for virulence under

controlled conditions. The following descriptions of the disease produced, the fungi, and their pathogenicity are based mainly upon these laboratory and greenhouse studies.

FUSARIUM ROOT-ROT CAUSED BY FUSARIUM SOLANI V. MARTII F. 2[3]

Fusarium solani v. *martii* f. *2* causes a dark brown or chocolate-colored lesion that is most prominent above the point of seed attachment on the stem, but which may extend below on the tap root and rootlets. Infection frequently takes place thru the seed and extends upward into the stem and downward into the root system (Fig. 1). In early stages of disease, the discolored portion is not materially shrunken, but in the later stages shrinking usually takes place. The fungus may invade the water-conducting tissue, causing a bright orange-red or brown discoloration extending to the first node. This vascular discoloration is not a general symptom. Infection tests indicated that it frequently was produced by a combination of *F. solani* v. *martii* f. *2* and other Fusaria. The Fusarium rot fungus is often found in associ-

FIG. 1.—FOOT- AND ROOT-ROT OF THOMAS LAXTON PEAS PRODUCED IN ARTIFICIALLY INFESTED, STERILIZED SOIL WITH A PURE CULTURE OF *Fusarium solani* v. *martii* f. *2*.

Note healthy cotyledons on control plant (left) and rotted cotyledons on diseased plant. The symptoms of disease are typical of those produced in field-infected plants.

[3]*Fusarium solani* f. *pisi* (Jones) S. and H. (23).

ation with *Aphanomyces euteiches* and other root-rot organisms.

All typical strains of *Fusarium solani* v. *martii* f. *2* sporulate freely on ordinary potato dextrose agar. Dense masses of spores with scant development of a cartridge buff mycelium are typically developed over the agar slant. The color[4] of the spore masses on hard potato dextrose agar in cultures 20 to 35 days old varies somewhat with the different strains. These masses are typically a dusky, dull bluish green with some dark delft blue. Certain strains have dark American green and deep olive buff or olive pionnotes masses, while others have cartridge buff and cream buff masses of pionnotes with or without some dusky, dull bluish green. The agar in most cases remains clear, but some strains at times impart a deep vinaceous to dark vinaceous or neutral red color to the medium. On rice, at the same age, little aerial mycelium is present. A stroma varying in color develops over the rice. The color characters typically include sorghum brown to a light seal brown or Saccardo's umber and sepia with light grayish vinaceous, pinkish buff, salmon buff, shell pink, or some yellow ocher mixed in. Pionnotes masses of pinkish buff, salmon buff, or apricot buff and, in some cases, vinaceous rufous are generally produced. Sclerotia covered with a cartridge buff or light seal brown mycelium may or may not develop.

Little significant variation in morphology was found in cultures of the pathogenic strains grown in daylight on potato dextrose agar. Typically, from 60 to 90 per cent of all spores in pionnotes are 3-septate. The average size of spores when grown on hard potato dextrose agar was 35.5 × 5.00 μ with a variation of 32.9 to 39.5 × 4.85 to 5.25 μ. In normal cultures, microconidia are not numerous and chlamydospores are present in conidia or the mycelium (Fig. 2).

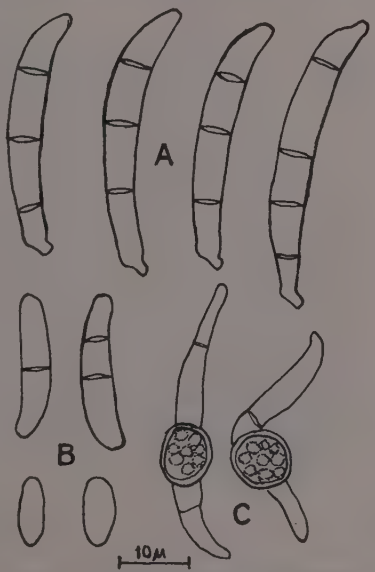

FIG. 2.—TYPICAL SPORES OF *Fusarium solani* v. *martii* F. *2*.
A, macroconidia; B, microconidia; C, chlamydospores.

[4]Color determinations were made with the aid of Ridgway's Manual (20).

From 1937 to 1941, type strains or fungi agreeing with the foregoing description were isolated from various sources and tested for virulence in a series of experiments in nutrient culture solutions, in pots of soil in a climate laboratory with controlled temperatures and moisture concentrations, and in pots of soil in the greenhouse. The results of the nutrient culture tests are presented in Table 5. The data on emergence from infested soil, amount of root-rot, and growth of two varieties of peas are given in Table 6. The fungi used in the tests were isolated in 1937 and 1938.

All fungi tested in the nutrient cultures (Table 5) and in soil in a climate laboratory (Table 6) caused a severe root-rot and stunting of both varieties of peas (Figs. 3 and 4). Each strain had the ability to invade pea plants but differed distinctly in virulence. For example, strains No. 1 from Penn Yan and No. 4 from Mt. Morris appeared

TABLE 5.—NUTRIENT CULTURE SOLUTION TESTS WITH DIFFERENT STRAINS OF *Fusarium solani* V. *martii* F. 2.*

CULTURE NO.	SOURCE OF CULTURE	RUN	ROOT-ROT, PER CENT	AV. SIZE OF PLANTS, CM
		Wilt-resistant Perfection		
1	Penn Yan	1	100	1.31
2	Geneva	1	100	1.81
	Control	1	0	6.29
3	Perry	2	100	4.51
	Control	2	0	4.86
4	Mt. Morris	3	100	1.10
	Control	3	0	5.51
5	Geneva	4	100	0.60
	Control	4	0	4.48
		Thomas Laxton		
1	Penn Yan	1	100	0.42
2	Geneva	1	100	6.90
	Control	1	0	13.20
3	Perry	2	100	0.34
4	Mt. Morris	2	100	0.10
5	Geneva	2	100	0.31
	Control	2	0	18.80

*10 plants per beaker.

FIG. 3.—NUTRIENT CULTURE SOLUTION TESTS WITH DIFFERENT STRAINS OF *Fusarium solani* v. *martii* f. *2.*

Severe root-rot and stunting of plants were produced by the various type strains used. From left to right: Control, strain No. 4, strain No. 5, and strain No. 3. Photographed April 6, 1939.

FIG. 4.—CLIMATE LABORATORY INOCULATION TESTS WITH DIFFERENT STRAINS OF *Fusarium* v. *martii* f. *2, Rhizoctonia solani,* AND *F. oxysporum.*

Demonstrating the ability of strain No. 4, *F. solani* v. *martii* f. *2*, to produce severe seed decay at a soil moisture of 22 per cent (dry weight basis), while strain No. 5 caused chiefly a severe root-rot and death of some of the young plants. *R. solani*, strain No. 2, produced little infection and the *F. oxysporum* strain no infection. Left row: Pot 1, strain No. 2, *R. solani;* pots 2 and 3, strain No. 5, *F. solani* v. *martii* f. *2*. Right row: Pot 1, strain No. 4, *F. solani* v. *martii* f. *2;* pots 2 and 3, *F. oxysporum* strain. Photographed April 28, 1939.

TABLE 6.—CLIMATE LABORATORY TEST WITH DIFFERENT STRAINS OF *Fusarium solani* v. *martii* f. 2.*

CULTURE NO.	SOURCE OF CULTURE	RUN	EMERGENCE, PER CENT	ROOT-ROT, PER CENT	AV. WEIGHT OF PLANTS, GRAMS
		Unsterilized Virgin Soil			
3	Perry	1	98	96.0	1.05
	Control	1	100	6.6	1.15
4	Mt. Morris	2	0†	—	—
5	Geneva	2	86	72.0	0.65
	Control	2	92	0.0	0.85
		Sterilized Soil			
1	Penn Yan	1	0†	—	—
2	Geneva	1	88	—	—
	Control	1	86	—	—
3	Perry	2	82	—	—
4	Mt. Morris	2	0†	—	—
5	Geneva	2	90	—	—
	Control	2	98	—	—

*Soil moisture 22 per cent (dry-weight basis); temperature, 18° C.
†Severe seed decay.

to be much more harmful, both in nutrient solution and in soil, than the others. Both caused severe seed decay, whereas other strains caused root-rot but very little or no injury to seed planted in infested soil (Figs. 4 and 9). The first climate laboratory test listed in Table 6 was made in unsterilized virgin soil, but the results on seed decay were confirmed in the second test made by adding pure cultures to sterilized soil. Positive re-isolations were made of all fungi used in the tests.

To check further on the pathogenicity and the presence of a varying degree of virulence within strains, six new isolants obtained in 1940 were used in greenhouse tests. All were isolated from infected pea plants except one which came from a root-rotted California red kidney bean growing in an infested field at Mt. Morris. These strains differed as much in their virulence as those isolated in previous years. All seeds were sown in infested soil on the same day. One pea strain caused severe stunting and drying within 21 days, whereas two others did not produce this effect for 29 days. The other pea strains never

did kill plants nor materially reduce growth in the 47 days before they were removed for observation. One strain isolated from a diseased pea growing in a soil virgin to pea culture at Junius and mentioned before proved to be pathogenic to peas. These tests also indicated that infection of the foot and root of plants may be initiated either thru the seed or by direct infection of the root system (Fig. 1). Re-isolations were made from all diseased plants, and microscopic examinations were made to be certain that Pythium or Aphanomyces had not contaminated the tests.

The strain isolated from a California red kidney bean proved to be extremely pathogenic to peas. In other tests not reported here, it caused root-rot of dry beans. This observation is of considerable practical importance from a rotation standpoint.

APHANOMYCES ROOT-ROT CAUSED BY APHANOMYCES EUTEICHES

Aphanomyces root-rot is characterized by a soft cortex rot of the roots and foot or lower stem of the plant. In early stages of the disease affected parts may have a translucent, yellowish, water-soaked appearance. In later stages, the infected cortical tissue decays, causing a stoppage of root growth and a resultant stunting of the plants. Plants in this condition may be readily pulled out of the soil, leaving the decayed cortex behind. In severe cases, leaves may turn yellow and plants may wilt and die. Where the fungous attack is on older plants, they may continue growth under favorable conditions and produce a partial crop.

Frequently, only the root of the plant below the seed attachment is attacked by Aphanomyces. This is true especially when the stem above the seed is infested by the Fusarium root-rot organism. A combination of these organisms frequently occurs in New York soils.

Aphanomyces euteiches produces a medium scant, whitish, aerial mycelium on potato dextrose agar. A somewhat velvety or felty and at times leathery cartridge buff stroma is formed on the surface. Few spores are produced on this agar. On hard corn meal agar, the mycelial growth is even less, consisting of rather coarse strains of mycelium spreading over the slant. No aerial mycelium is produced. An abundance of oogonia, antheridia, and oospores is produced on corn meal agar (Fig. 5). The oogonia are subspherical and measure from 25 to 35 μ in diameter and the antheridia are often branched. Oospores are thick-walled, subspherical, and measure 23.0 to 24.5 × 24.5 to 27.5 μ.

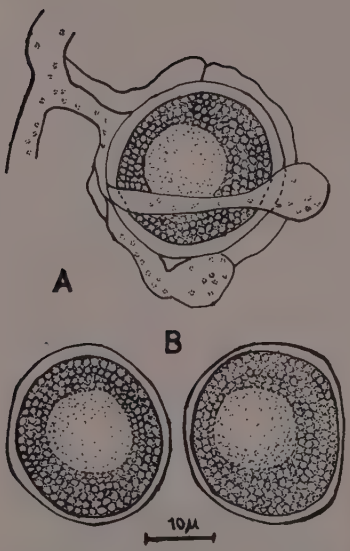

FIG. 5.—TYPICAL SPORES OF *Aphanomyces euteiches* FROM AN OLD CULTURE OF THE FUNGUS ON HARD, CORNMEAL AGAR.
A, oogonium with antheridia; B, oospores.

nation of the diseased tissue showed the presence of an abundance of oospores of the fungus (Fig. 6). Two replantings made in the soil of these pots resulted in the development of severe disease. Pure cultures of the fungus were isolated from diseased material.

PYTHIUM ROOT-ROT CAUSED BY PYTHIUM ULTIMUM

Plants affected with Pythium root-rot are characterized by a somewhat water-soaked, translucent, and softened diseased tissue extending above and below the

Pure cultures of the fungus isolated from infected plants proved it to be similar to the organism reported from various parts of the United States. Since the parasitism of *Aphanomyces euteiches* on peas has been well established (5, 6, 7, 8, 9), only a few infection tests were made to make certain that the true pathogen was being investigated. Sterilized soil in pots was infested with *A. euteiches* naturally infested pea roots. Within 30 days, 100 per cent root-rot developed and microscopic exami-

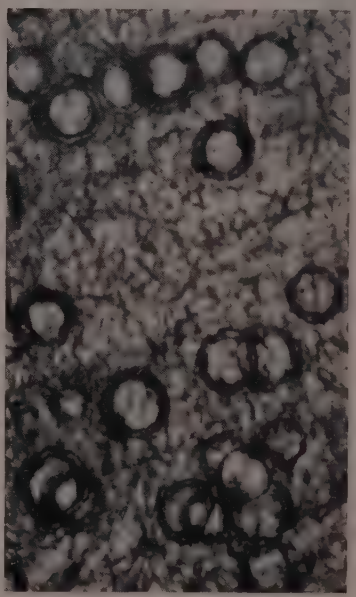

FIG. 6.—OOSPORES OF *Aphanomyces euteiches* IN THE CRUSHED CORTEX OF AN INFECTED SURPRISE PEA ROOT. Approximately × 250. Photographed October 9, 1939.

FIG. 7.—FOOT- AND ROOT-ROT OF SURPRISE PEAS PRODUCED IN ARTIFICIALLY INFESTED STERILIZED SOIL WITH A PURE CULTURE OF *Pythium ultimum*, STRAIN NO. 3.

Note typical translucent-appearing rot and absence of cotyledons which have decayed. Photographed June 20, 1939.

agar (Fig. 8). The average measurements of oospores from the virulent strains grown on this media were 19 to 20 μ with a variation of 15 to 22.5 μ in diameter. This organism as well as a number of different species of Pythium commonly found associated with diseased plants were used in inoculation tests.

Infection tests with strains of *Pythium ultimum* and other *Pythium* spp. collected from various parts of the State were made in nutrient culture solutions and in pots of soil in the climate laboratory. Seed attachment (Fig. 7). In early stages, the infected parts are straw-colored to light brown and in later stages the tissues shrink and darken, turning a light blackish brown. Few secondary roots are produced on badly affected plants. *Pythium ultimum* is frequently isolated from diseased field plants. It is often associated with plants affected by the Fusarium or Aphanomyces root-rot.

Pure cultures of *Pythium ultimum* when grown on hard potato dextrose agar produce a dense growth of aerial white mycelium and a cartridge buff, tough, leathery stroma over the surface. On hard cornmeal agar, the growth is less extensive with white, fine, cottony, aerial mycelium and little, leathery growth. Oogonia, antheridia, and oospores are produced in abundance on hard cornmeal

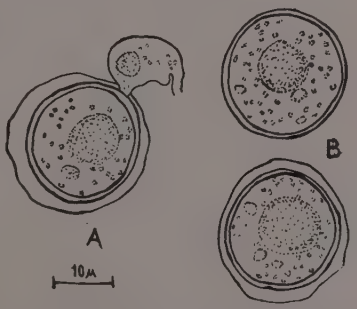

FIG. 8.—TYPICAL SPORES OF *Pythium ultimum* FROM AN OLD CULTURE OF THE FUNGUS ON HARD CORNMEAL AGAR.

A, Oogonium with antheridium; B, oospores.

tory. These tests showed the presence of *P. ultimum* strains which possessed the ability to cause severe seed decay and other strains which lacked this quality. The presence of strains varying in degrees of virulence in production of root-rot was indicated. The various other *Pythium* spp. produced no significant seed decay but some slight root-rot (Fig. 12). The results of these tests are presented in Tables 7 and 8.

TABLE 7.—NUTRIENT CULTURE SOLUTION TESTS WITH STRAINS OF *Pythium ultimum* AND *Pythium* SPP.

CULTURE No.	CULTURE	SOURCE OF CULTURE	ROOT-ROT, PER CENT	AV. SIZE OF PLANTS, CM
		Thomas Laxton		
1	*P. ultimum*	Perry	100	7.9
2	*P. ultimum*	Geneva	100	5.6
3	*P. ultimum*	Oaks Corners	100	7.1
4	*P. ultimum*	Gage	100	4.8
5	*P. ultimum*	Oaks Corners	100	6.1
6	*P.* sp.	Geneva	50*	10.8
	Control		0	18.8
		Wilt-resistant Perfection		
7	*P.* sp.	Geneva	40*	8.07
8	*P.* sp.	Geneva	60*	6.12
	Control		0	5.51

*Slight infection.

In the nutrient culture solution tests (Table 7), all strains of *Pythium ultimum* caused severe root-rot and a marked stunting. The other *Pythium* spp. showed much less ability to attack and to cause stunting of the peas. Soil infection tests summarized in Table 8 and run in duplicate for each fungus with 25 wilt-resistant Surprise pea seeds in each pot clearly showed the existence of strains that varied in virulence. *P. ultimum* strains 2, 3, and 5 produced 100 per cent seed decay in the unsterilized virgin soil and somewhat less in the sterilized soil series, while strains 1 and 4 apparently lacked this quality (Figs. 9 and 12). Less root-rot and stunting were in evidence on plants growing in the soil infested with the latter two fungi. The virulent cultures in these tests were the cause of seed decay more than root-rot. It is interesting to note that *P. ultimum* strains 3 and 5, isolated from diseased peas growing in virgin forest soil, were among the most virulent parasites, thereby verifying the fact that this organism as elaborated on before may be indigenous to soils new to pea

TABLE 8.—CLIMATE LABORATORY TESTS WITH STRAINS OF *Pythium ultimum* AND *Pythium* SPP.*

CULTURE NO.	CULTURE	SOURCE OF CULTURE	EMERGENCE, PER CENT	ROOT-ROT, PER CENT	AV. WEIGHT OF PLANTS, GRAMS
		Unsterilized Virgin Soil			
		Chamber 1:			
1	*P. ultimum*	Perry	82	85.3	0.92
2	*P. ultimum*	Geneva	0†	—	—
6	*P.* sp.	Geneva	92	21.6‡	1.21
	Control		100	6.6	1.15
		Chamber 4:			
3	*P. ultimum*	Oaks Corners	0†	—	—
4	*P. ultimum*	Gage	94	2.2	0.81
6	*P.* sp.	Geneva	96	6.2‡	0.90
7	*P.* sp.	Geneva	98	6.1‡	0.85
8	*P.* sp.	Geneva	98	2.1‡	0.81
	Control		96	0	0.91
		Chamber 5:			
5	*P. ultimum*	Oaks Corners	0†	—	—
	Control		92	2.0	0.85
		Sterilized Soil			
1	*P. ultimum*	Perry	46	56.5	—
2	*P. ultimum*	Geneva	8†	100.0	—
3	*P. ultimum*	Oaks Corners	10†	40.0	—
4	*P. ultimum*	Gage	88	52.3	—
5	*P. ultimum*	Oaks Corners	12†	100.0	—
6	*P.* sp.	Geneva	96	4.2‡	—
7	*P.* sp.	Geneva	98	4.1‡	—
8	*P.* sp.	Geneva	92	10.8‡	—
	Control		92	2.0‡	—

*Soil moisture 22 per cent (dry-weight basis); temperature, 18° C.
†Seed decay.
‡Slight infection.

culture. All *Pythium* spp. tested caused little, if any, significant seed decay and but slight root-rot that resulted in little or no stunting of the plants.

RHIZOCTONIA ROOT-ROT CAUSED BY RHIZOCTONIA SOLANI

Rhizoctonia solani typically causes brownish, often sunken and somewhat cracked, elongated lesions on the stem or foot of the plant below the ground surface (Fig. 10). These lesions less frequently extend below the seed attachment to the tap root and even to the secondary roots. During an extremely wet season with dense plant growth, the lower parts of the stems above the ground surface may be

FIG. 9.—CLIMATE LABORATORY INOCULATION TESTS WITH *Pythium ultimum, Fusarium solani* v. *martii* f. *2,* AND *Rhizoctonia solani.*

Severe seed decay produced by strain No. 2 of *P. ultimum,* while strain No. 1 caused little. Strain 3 of *F. solani* v. *martii* f. *2* produced some root-rot, while strain No. 1 of *R. solani* produced little root-rot. Left row: Pots 1 and 2, strain No. 3, *F. solani* v. *martii* f. *2;* pots 3 and 4, strain No. 1. *R. solani.* Right row: Pots 1 and 2, strain No. 1, *P. ultimum;* pots 3 and 4, strain No. 2, *P. ultimum.*

TABLE 9.—NUTRIENT CULTURE SOLUTION TESTS WITH STRAINS OF *Rhizoctonia solani.**

CULTURE	ROOT-ROT, PER CENT	AV. SIZE OF PLANTS, CM
Wilt-resistant Perfection		
Strain No. 1	30	6.0
Control	0	5.5
Strain No. 2	90	3.5
Control	0	5.5
Thomas Laxton		
Strain No. 1	40	10.5
Strain No. 2	60	14.5
Control	0	19.0

*10 plants per beaker.

attacked. A rot of the cotyledons of the seeds may be produced. The fungus is the sterile or Rhizoctonia stage of *Corticium vagum* v. *solani*. It grows well on potato dextrose agar, producing a dense growth of coarse, brown mycelium and an abundance of brown sclerotia. Differences in cultural characters exist between various isolants, thereby indicating different strains.

Infection tests were run in nutrient culture solutions and in pots of a soil in a climate laboratory with strains Nos. 1 and 2 of *Rhizoctonia solani* isolated from diseased plants growing near Albion and Seneca Castle, respectively. The data from these experiments, as presented in Tables 9 and 10, indicate that the fungi caused little damage under the conditions of the test. In the nutrient solutions, some stunting of the Perfection peas with 90 per cent root-rot was noted and severe stunting of Thomas Laxton was produced in cases where only 40 and 60 per

FIG. 10.—FOOT-ROT OF SURPRISE PEAS PRODUCED IN ARTIFICIALLY INFESTED, STERILIZED SOIL WITH STRAIN No. 2 OF *Rhizoctonia solani*.

Elongated, dark brown, somewhat dried and sunken lesions produced primarily on the foot of the plants. The roots were healthy and had been removed. Photographed March 4, 1939.

TABLE 10.—CLIMATE LABORATORY INOCULATION TESTS WITH STRAINS OF *Rhizoctonia solani*.*

CULTURE	EMERGENCE, PER CENT	FOOT-ROT, PER CENT	AV. WEIGHT OF PLANTS, GRAMS
Strain No. 1	96	21	1.22
Control	100	0	1.15
Strain No. 2	90	58	0.86
Control	90	0	0.85

*Soil moisture 22 per cent (dry-weight basis); temperature, 18° C.

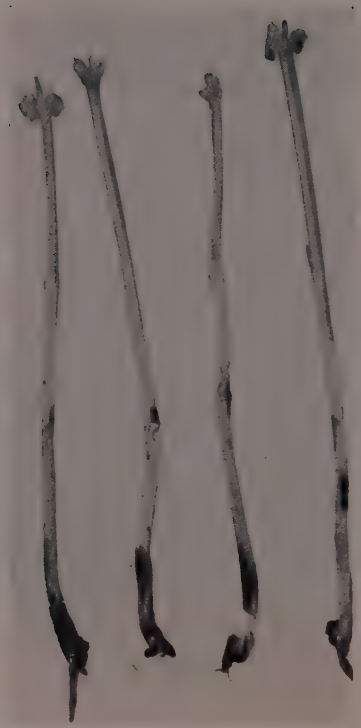

FIG. 11.—FOOT-ROT OF SURPRISE PEAS PRODUCED IN ARTIFICIALLY INFESTED, STERILIZED SOIL WITH A PURE CULTURE OF *Ascochyta pinodella*, STRAIN NO. 1.

Elongated, blackened blotches produced primarily on the foot of the plants. The root system was healthy and had been removed. Photographed March 2, 1939.

cent root-rot was present. This stunting was not reflected in the soil tests where from 21 to 58 per cent of the plants had root-rot (Figs. 4 and 9). No significant seed decay was noted. In an earlier test, conducted in soil with strain No. 1, stunting of plants was produced when 64 per cent foot-rot was produced. The rot in these tests was primarily confined to the foot of the plants above the seed attachment (Fig. 10), altho it did extend down on the tap root of some plants.

ASCOCHYTA ROOT-ROT CAUSED BY ASCOCHYTA PINODELLA

Ascochyta root-rot is characterized by elongated, black blotches produced on the foot of the plant between the ground surface and the seed attachment (Fig. 11). The tap root below the cotyledons may be attacked, but generally the infection is confined to the foot of the plant. The fungus may produce a leaf and pod spot.

Ascochyta pinodella produces light to dark brown, scattered pycnidia on diseased tissue. On hard potato dextrose agar cultures one month old, a thin, white mycelium is produced over the top of the slant with a black stroma below. Black pycnidia are scattered thru the stroma with a few cinnamon buff pycnidia at the edges of the growth. The spores are hyaline, single- or two-celled, and measure from 5 to 13 × 2.0 to 4.5 μ. No ascigerous stage of the fungus has been demonstrated.

Infection tests with two separate strains of the organism were made. Strain No. 1 was isolated from a plant growing in a diseased

field at Perry and strain No. 2 came from a plant collected south of Sodus. Both showed the same growth characters in culture. Tests in nutrient culture solutions with strain No. 1 showed that it primarily attacks the lower portion of the pea stem above the seed attachment, while the root system remained clear but retarded in growth. The fungus produced 90 per cent infection of wilt-resistant Perfection peas with little stunting of the plants and 70 per cent foot-rot on Thomas Laxton peas with a distinct retardation of growth. The check plants in the latter test were 6 cm larger than the infected plants. Infection in pots of soil with a moisture content of 22 per cent (dry weight basis) in a climate laboratory was characterized by elongated, blackened blotches above the seed attachment and a distinct retardation of growth (Fig. 12). Similar results were obtained in infested pots of soil placed in the greenhouse where culture No. 2 produced from 45 to 75 per cent disease of 10 Thomas Laxton seeds planted in three pots. Emergence of plants was normal in each instance, but the plants were severely stunted after 45 days of growth, measuring on an average of 5.5 cm less than the plants in the control noninfested pots. The organisms used for all infection tests were readily reisolated.

FIG. 12.—CLIMATE LABORATORY INOCULATION TESTS WITH *Fusarium oxysporum* STRAINS; *Ascochyta pinodella* (STRAIN 1); *Pythium* SP.; AND *Pythium ultimum*.

Left row: Pot 1, *F. oxysporum;* pots 2 and 3, *Ascochyta pinodella*, strain No. 1. Right row: Pot 1, *Pythium* species, strain No. 6; pots 2 and 3, *Pythium ultimum*, strain No. 3. Photographed March 2, 1939.

FUSARIUM SPECIES COMMONLY ASSOCIATED WITH ROOT-ROT

In the course of isolations made from diseased plants, a number of Fusaria commonly were found associated with the known pathogens. Since most of these have been reported pathogenic to peas, a series of inoculation tests was conducted to establish their role. Strains of the following different organisms isolated in 1937 and 1940 from diseased plants collected at Perry and Geneva were used: *Fusarium poae, F. sporotrichioides, F. arthrosporioides, F. anguioides, F. scirpi* v. *acuminatum, F. equiseti, F. graminearum, F. culmorum,* and *F. oxysporum.*

In nutrient culture solution tests the various strains of the fungi appeared to be slightly pathogenic to wilt-resistant Perfection and Surprise peas under the conditions of the tests. Both slight root-rot and stunting of the plants were produced by most strains of the various species. The soil tests conducted in the greenhouse at a temperature varying from 70° to 75° F with cultures Nos. 1 to 6 isolated in 1937 and with cultures Nos. 7 to 17 isolated in 1940, as summarized in Table 11, present a different picture.

TABLE 11.—GREENHOUSE TESTS WITH DIFFERENT SPECIES AND STRAINS OF *Fusarium.**

CULTURE NO.	ORGANISM	EMERGENCE, PER CENT	ROOT-ROT, PER CENT	AV. SIZE OF PLANTS, CM
	Surprise, 20 Seeds			
1	*F. poae*	95	5.0	25.4
2	*F. arthrosporioides*	100	0	27.9
3	*F. anguioides*	90	5.0	24.2
4	*F. scirpi* v. *acuminatum*	90	0	25.4
5	*F. equiseti*	100	0	26.7
6	*F. graminearum*	80	0	24.8
	Control (90 seeds)	90	0	26.1
	Thomas Laxton, 30 Seeds			
7	*F. sporotrichioides*	93	0	46.9
8	*F. sporotrichioides*	100	0	54.6
9	*F. anguioides*	97	0	48.8
10	*F. culmorum*	93	0	47.7
	Control	100	0	44.5†
11	*F. oxysporum*	93	0	43.4
12	*F. oxysporum*	100	0	43.9
13	*F. oxysporum*	100	0	44.7
14	*F. oxysporum*	90	0	45.1
15	*F. oxysporum*	97	0	47.8
16	*F. oxysporum*	100	0	44.4
17	*F. oxysporum*	93	0	45.2
	Control	100	0	43.6

*Sterilized soil in pots.
†Red spider injury.

In this test *Fusarium poae* and *F. anguioides*, Nos. 1 and 3, respectively, slightly infected the roots of Surprise peas. Strain No. 9 of *F. anguioides*, however, failed to infect Thomas Laxton peas. It is interesting to note that none of the seven strains of *F. oxysporum* tested in the soil were pathogenic for these organisms are consistently isolated from diseased plants (Figs. 4 and 12).

The soil tests would indicate that the various Fusaria tested are not normally a factor in the production of pea root-rot. Similar results were obtained in other soil test series not reported.

DISCUSSION

The investigations conducted during the past years on the distribution of pea root-rot organisms show that at least 14 different fungi associated with diseased plants are widely distributed thruout western New York pea-growing areas. Practically all organisms reported on peas in the United States and elsewhere were found to be present in this region. These included the following: *Fusarium solani* v. *martii* f. *2*, *Aphanomyces eutciches*, *Pythium ultimum*, *Rhizoctonia solani*, *Ascochyta pinodella*, *Fusarium poae*, *F. sporotrichioides*, *F. arthrosporioides*, *F. anguioides*, *F. scirpi v. acuminatum*, *F. equiseti*, *F. culmorum*, *F. graminearum (Gibberella saubinetii)*, and various strains of *F. oxysporum*.

Tests for virulence showed that the first five organisms in the list are the ones responsible for disease. While published data show that some of these fungi were first present in western New York soils in 1924, a number at least were in the soil at a much earlier period. In fact, *Fusarium solani* v. *martii* f. *2* and *Pythium ultimum* must have been present for a long time since both were found in virgin soil. Notes on pea root-rot made by F. C. Stewart of this Station in 1897 showed the presence of peas with blackened bases of stems collected at Milton, N. Y. He recorded the disease in the Geneva region in 1902 and 1904 and severe infection in 1911. Later, in 1917, he made note of a Pythium in diseased roots collected at Geneva.

The detailed studies conducted from 1931 thru 1941, as presented in Table 1, give a clear picture of the distribution of the pathogens and other fungi commonly associated with pea root-rot. They show that the active parasites, *Fusarium solani* v. *martii* f. *2*, *Aphanomyces cutciches*, *Pythium ultimum*, and *Rhizoctonia solani* were generally widespread thruout the commercial pea-growing areas. *Ascochyta pinodella* was found only occasionally, its scarcity apparently being

due to the general use of western-grown seed that was free of the organisms. Of the various Fusaria isolated *F. anguioides, F. scirpi* v. *acuminatum,* and *F. equiseti* appeared to be rather generally widespread. Strains of *F. oxysporum* always were found in association with diseased plants. The near-wilt organism *F. oxysporum* f. *8* was included in this group but is not considered here. At times it is associated with the true root-rot organisms in diseased plants. Since the disease surveys, isolations, and microscopic examinations made over a period of years clearly show that the important pea pathogens are present thruout all of the larger commercial pea areas of the State, they must be taken into consideration in a management of pea culture.

Studies showed that the destructive organisms *Fusarium solani* v. *martii* f. *2, Aphanomyces euteiches, Pythium ultimum,* and *Rhizoctonia solani* apparently are not limited to certain soil types and soil reactions within the pea areas investigated. Since the commercial pea acreage studied is located primarily on Ontario loam, fine sandy loam, silty clay loams, and silt loams with slightly acid (pH 6.5 to 6.9), neutral (7.0), or slightly alkaline (7.1 to 7.5) reactions, the main part of the data was secured from these areas. A number of areas lighter in soil texture and with medium acid (pH 5.4 to 6.4) reactions also were investigated, but they were in the minority. Quite a pea acreage is located on medium acid soil (pH 5.4 to 6.4) and some on strongly acid soil (pH 4.5 to 5.2) lighter in texture than the average New York pea soil. It is possible that the disease relationship in such soil may be different. The organisms and disease, however were found in a variety of soils with reactions ranging from pH 5.4 to 7.48. Detailed, controlled experiments would have to be run to determine accurately the relation of disease and pathogen to soil type and reactions. A survey of healthy fields of various soil types and soil reactions should give interesting correlations for the present data does not include soil types in which disease is not found.

Tests indicate that *Aphanomyces euteiches* may be of relatively little importance during an extremely dry season, even tho the soil is infested with the organism. On the other hand, *Fusarium solani* v. *martii* f. *2* apparently is always active, thereby accounting year after year for the majority of root-rot. According to the data obtained, *Pythium ultimum, Rhizoctonia solani,* and *Ascochyta pinodella* appeared to be more prevalent in a wet season as compared with a drier season.

Haenseler (8) has shown that root-rot caused by *Aphanomyces euteiches* is rarely found in New Jersey before the middle of May and that a minimum daily temperature of at least 14°C (57.2°F) lasting over a period of several days is necessary for infection. He reported (7) that root-rot was favored by a high soil moisture with 30 per cent saturation close to a minimum for the disease.

Smith and Walker (22) report that optimum temperature for disease development on plants grown in sand was found at 24°C (75.2°F) and 28°C (82.4°F). No infection was noted at 12°C (53.6°F) during an 11-day period. They reported further that in infested soil practically no infection occurred when the moisture was maintained at 45 per cent of the water-holding capacity. At 75 per cent of moisture-holding capacity infection was quite severe.

Jones (12) has shown that infection by *Fusarium solani* v. *martii* f. *2* may take place at 12°C (53.6°F), but that conspicuous lesions develop at 18°C (64.4°F) and that killing takes place at 24°C (75.2°F). He concluded that the organism prefers a high soil temperature above 18°C (64.4°F) and is not much affected by variations in soil moisture within the limits favorable for plant growth.

These studies apparently explain why no infection by *Aphanomyces euteiches* took place in the fields mentioned above under dry soil conditions and why *Fusarium solani* v. *martii* f. *2* was found to be active under all conditions investigated. They also indicate that peas should be planted as early as possible in order to take advantage of the cooler soil temperatures that are unfavorable to fungus development.

Laboratory investigations conducted with peas grown in a forest soil virgin to pea culture showed that both *Fusarium solani* v. *martii* f. *2* and *Pythium ultimum* were indigenous to this soil. It was further demonstrated that these organisms multiplied in this soil during pea culture. These studies were confirmed in comparative variety plantings made on heavily infested soil and in cultivated fields where peas had never been grown. Almost 100 per cent root-rot developed in peas grown in the soil previously cropped to peas, while only a few scattered cases of infection occurred in the soils new to pea culture. Disease was produced by *F. solani* v. *martii* f. *2*, *Aphanomyces euteiches*, *P. ultimum*, and *Rhizoctonia solani* in the old soil, while *F. solani* v. *martii* f. *2*, *P. ultimum*, and *R. solani* were found to be responsible for the few cases of disease in the new soil.

These tests showed that certain soils naturally may contain at least *Fusarium solani* v. *martii* and *Pythium ultimum* and that the severity of root-rot seems to be dependent upon a build-up of the destructive fungi. The organisms are not present in all soils new to pea culture for disease is not present in many fields. One problem of the pea grower apparently is to keep the population of disease-producing organisms down to a minimum when they are present in the soil. The advisability of planting new soils and then keeping them relatively free of pathogens by a long rotation appears to be of importance. Some large operators have found it practical to select new lands for pea culture and so to manage these with small scattered acreages that the same piece of land will not be planted to peas before a lapse of at least 10 years. Such practices have been giving productive results undoubtedly because they prevent a build-up of the disease-producing organisms and thereby reduce the severity of the disease. Further studies are essential to prove this point.

Investigations on the relation of pathogens to rotations conducted on the Station's canning crops farm at Geneva from 1937 thru 1941 showed that the pathogens and disease were not eliminated by the 3-, 4-, or 5-year rotations practiced. These fields had grown peas in rotation for the past 16 years and were thoroly infested with the chief root-rot organisms. Isolations and microscopic examinations of diseased plants revealed the presence of *Fusarium solani* v. *martii* f. *2, Aphanomyces euteiches, Pythium ultimum,* and *Rhizoctonia solani* under most conditions, except during a dry season. Under the latter circumstances, *A. euteiches* was not found in diseased plants, even tho the fungus was known to be present in the soil. In spite of its inactivity during a dry year, the yields were lower than when it was active. The low yields probably were due to the effects of insufficient moisture during the dry seasons, resulting in a poor growth, as much as from the attacks of root-rot fungi.

The profitable yields of peas obtained during favorable seasons on plots which were properly fertilized would indicate that the pathogens had been reduced in number during a 3- to 5-year rotation sufficiently to permit such yields. Undoubtedly, higher yields would have been obtained had the pathogens been still further reduced. The studies did not show what reductions in the population of the pathogens took place in the various rotations. Detailed investigations on diminution of the parasites with different types of rotations should

give valuable information in this regard. In spite of the presence of most of the pathogens in the soil, profitable yields were obtained from the best fertilized plots during each favorable growing season from 1938 thru 1941 (Table 4). During the excellent growing season of 1938, the fertilized plot yielded 4,983 pounds of shelled Pride peas per acre and the nonfertilized field yielded 2,617 pounds. The 1939 season was very dry, resulting in failures and in poor yields. Even under these conditions, the best fertilized field of Pride peas produced 1,505 pounds while the nonfertilized plot was a failure with 542 pounds of peas. In the good growing seasons of 1940 and 1941, profitable yields of 1,798 to 3,290 pounds per acre were produced from the fertilized plots, while the nonfertilized plots only produced from 783 to 1,772 pounds of shelled peas per acre. The present studies indicate the importance of a reduction in the population of disease-producing organisms by a proper rotation combined with the maintenance of a high fertility level for profitable production of peas in infested areas where they have been grown over a period of years.

Pathogenicity investigations clearly demonstrated that *Fusarium solani* v. *martii* f. *2*, *Aphanomyces cuteiches*, *Pythium ultimum*, *Rhizoctonia solani*, and *Ascochyta pinodella* are the active parasites. The other Fusaria found associated with diseased plants were shown to be nonpathogenic in soils or, in the case of a few, only slightly pathogenic.

The infection tests gave a clear-cut picture of the ability of *Fusarium solani* v. *martii* f. *2* to produce a severe type of root-rot as well as seed decay (Figs. 1, 3, and 4). Such cases of infection are present commonly thruout the infected pea fields of New York State. Some of the strains isolated under field conditions varied in their ability to cause seed decay, stunting, and death of the plants. Contrary to the generally accepted idea, some strains attack both peas and dry beans; so dry beans should be excluded from the rotation in pea-growing areas. No other hosts of the organisms have been demonstrated.

The fact that strains exist which vary in degree of virulence would indicate that strains of increasing virulence might be developed in repeated plantings of peas in the same area. The inoculation tests also showed that infection of the foot and root of plants may be initiated thru the seed as well as by direct infection of the root system (Fig. 1). The use of seed protectants to prevent seed decay, therefore, should aid in the production of healthier plants which should be able better to withstand the effects of the root-rot organisms.

Infection tests with *Aphanomyces cuteiches* demonstrated its ability to cause severe root-rot and even death of the plants. The affected roots in all cases were found to be thoroly infested with oospores (Fig. 6). Studies of pure cultures isolated from diseased peas proved that the New York organism is similar to that found in other parts of the United States. Linford (17) reported the following leguminous plants grown from seed in naturally infested soil to be susceptible: Alfalfa *(Medicago sativa),* sweet clover *(Melilotus alba),* sweet peas *(Lathyrus odoratus), L. latifolius, Lathyrus* sp. (native of northern Utah), vetch *(Vicia angustifolia), V. sativa, V. pannonica, V. monantha, V. gigantea, V. fulgens, V. ervilia* and *V. dasycarpa.* None of these hosts were reported to be as susceptible as the pea, but the organism may live as a weak parasite on the roots. Their relation to rotations needs further study.

Investigations conducted with *Pythium ultimum* and various *Pythium* spp. showed that the former was a distinct parasite and that the latter were saprophytic or, in a few instances, only slightly parasitic. The presence of strains of *P. ultimum* varying in their ability to cause seed decay and in their degree of virulence relative to root-rot was demonstrated (Fig. 9). While the inoculation tests have shown that *P. ultimum* under certain conditions may produce a severe type of foot- and root-rot generally arising from the infected seed (Fig. 7), judging from the combined laboratory tests and field behavior, it apparently plays its chief role as a pea seed decay organism and seedling parasite.

The laboratory inoculation tests in nutrient solutions and in soil indicated that *Rhizoctonia solani* under the conditions of the tests was only a weak parasite. Both strains of the fungus used in these studies proved capable of causing infection that was confined largely to the foot of the plant above the seed attachment (Fig. 10). The laboratory results apparently portray field behavior, for the disease rarely was observed in a serious form under field conditions.

Tests with two strains of *Ascochyta pinodella* showed that it may cause a foot-rot. A distinct blackening of the stem below the ground surface (Fig. 11) was evident along with severe stunting. During the past few years, the fungus has not been widespread in fields. Its presence in isolated fields indicated that it was brought in on the seed, and that if contaminated seed is used it might again become important.

None of the various species and strains of Fusaria, other than the important *Fusarium solani* v. *martii* f. *2,* apparently are responsible

for disease. Even tho they may be found consistently associated with diseased plants, the inoculation tests indicate that they are secondary organisms. The various strains of *F. oxysporum* that are present in practically 100 per cent of the diseased roots were found to be saprophytic.

SUMMARY AND CONCLUSIONS

Isolations and microscopic examinations have shown that practically all root-rot organisms reported on peas in the United States and from various parts of the world are widely distributed in the older pea soils of western New York.

Inoculation experiments and field studies have shown the following organisms, listed in order of importance, to be primarily responsible for disease in peas in New York State: *Fusarium solani* v. *martii* f. *2, Aphanomyces euteiches, Pythium ultimum, Rhizoctonia solani,* and *Ascochyta pinodella.* None of the other Fusaria commonly associated with root-rot were found to cause serious disease under greenhouse or field conditions.

The destructive organisms, *Fusarium solani* v. *martii* f. *2, Aphanomyces euteiches, Pythium ultimum,* and *Rhizoctonia solani* were isolated from plants growing in a variety of soils differing in texture and reaction (pH 6.25 to 7.48) and the first three in a few soils with a pH of 5.4 and 5.5.

The studies show that *Fusarium solani* v. *martii* f. *2* apparently is always active, thereby accounting year after year for the majority of disease outbreak, and that *Aphanomyces euteiches* may be of relatively little importance during an extremely dry season even tho the soil is infested with the organism.

Pathogenic fungi cause less damage at lower temperatures. Peas should be planted as early as possible in order to take advantage of the cooler soil temperatures that are unfavorable to fungous development.

Fusarium solani v. *martii* f. *2, Pythium ultimum,* and *Rhizoctonia solani* were found to be indigenous to certain virgin pea soils. The first two organisms were shown to multiply in the soil with repeated pea plantings. Since a number of the important pathogens may be present naturally in soils to be planted with peas, one problem of the pea grower is to keep their population down to a minimum. This apparently may best be accomplished by a proper crop rotation.

A 6-year study of fields on the Station's canning crops farm at Geneva where peas have been grown in rotation over a period of 16 years showed that the important root-rot organisms were not entirely eliminated by a 3-, 4-, or 5-year rotation. Commercially profitable yields were obtained during favorable growing seasons on properly fertilized fields in spite of the presence of the pathogens.

The importance of a crop rotation to reduce the population of the pathogens in the soil, along with the proper maintenance of a high fertility level, seems to be of prime consideration in disease control.

Since the root-rot organisms are widely distributed thruout the pea-growing areas of New York State and are not entirely eliminated by a 3- to 5-year rotation, peas should be planted only on selected, properly prepared, sufficiently fertilized, well-drained soils, not previously planted to peas for many years. Peas grown under adverse conditions on infested soil are very subject to root-rot.

Pathogenicity investigations proved the existence of strains of *Fusarium solani* v. *martii* f. *2* and *Pythium ultimum* varying in their ability to cause pea seed decay in moist soils and root-rot with stunting and death of plants.

One strain of *Fusarium solani* v. *martii* f. *2* isolated from root-rot of a California red kidney bean was found to be extremely pathogenic to peas and capable of attacking and living as a weaker parasite on various dry beans. Dry beans, therefore, should be excluded from a rotation in fields where peas are planted.

Fusarium solani v. *martii* f. *2* and *Pythium ultimum* frequently enter the foot and root of plants thru the decaying seed.

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